A 21st Century Approach to Reliability Program Overview

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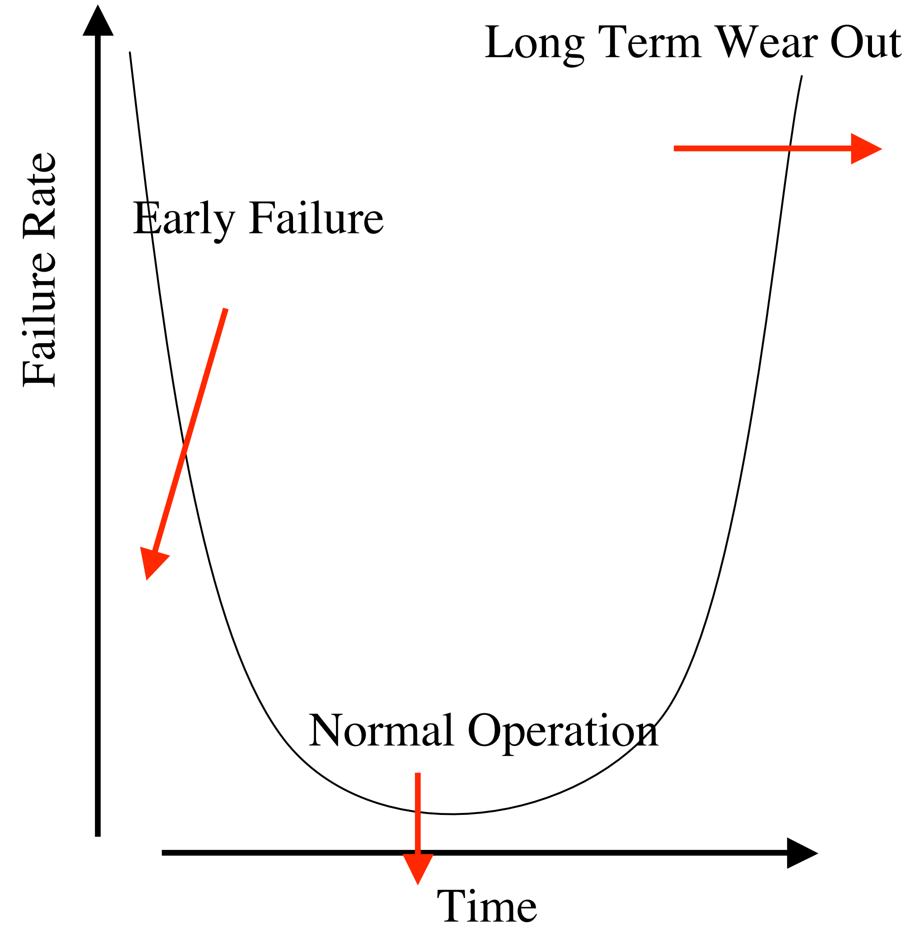
Outline

- Background
- Goals and Objectives
- Status
- Research Highlights

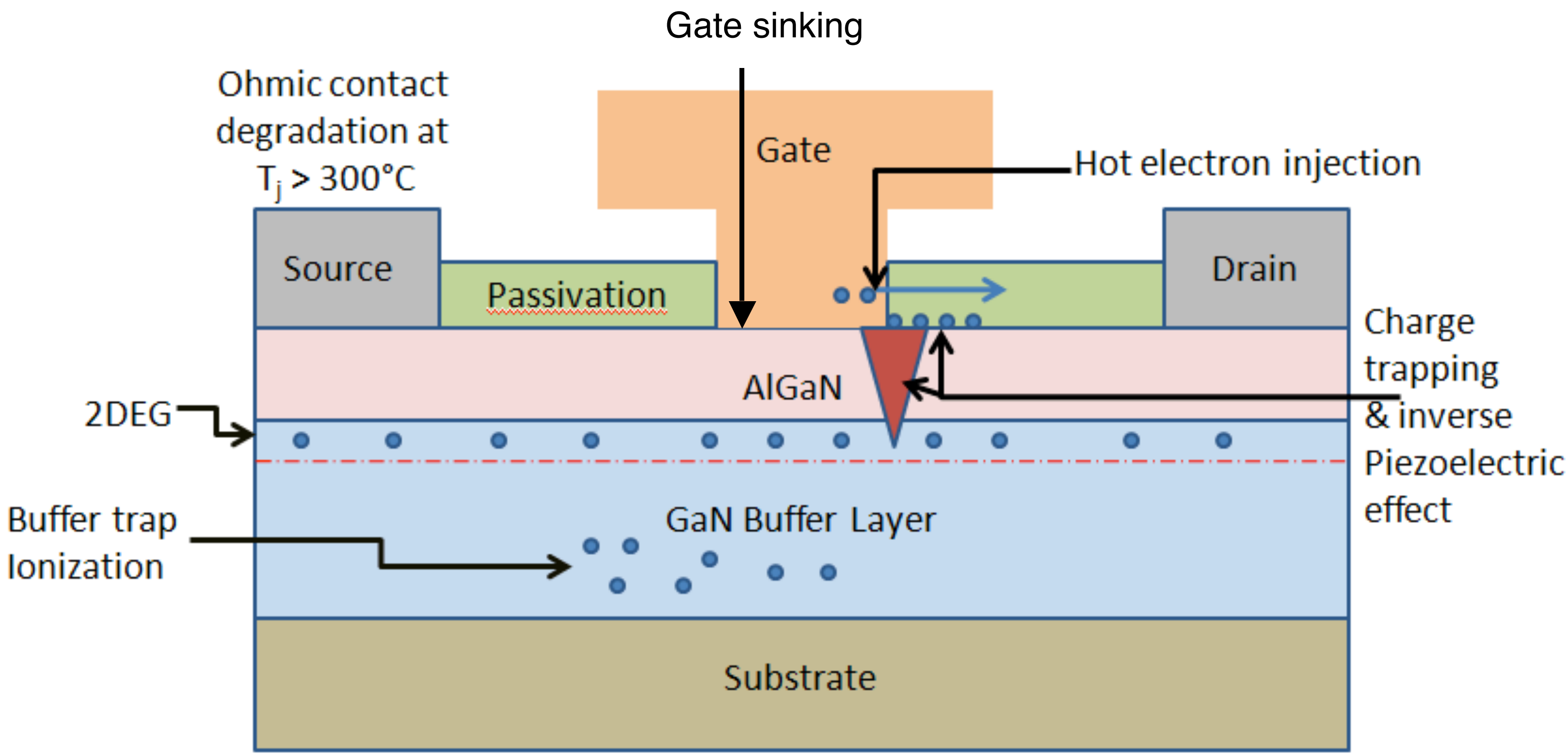
Electronic Lifetime - Bath Tub Curve

- Industry Objectives
  - Reduce Early Failure
  - Reduce Random Failure
  - Length time to Wear Out
- MURI Research
  - Develop early detection tools Canary in the coal mine
  - Provide Understanding of Failure to reduce random components
  - Identify causes of long term wear
  - Develop better accelerated testing



Push the curve in the red directions

Degradation of GaN HEMT's

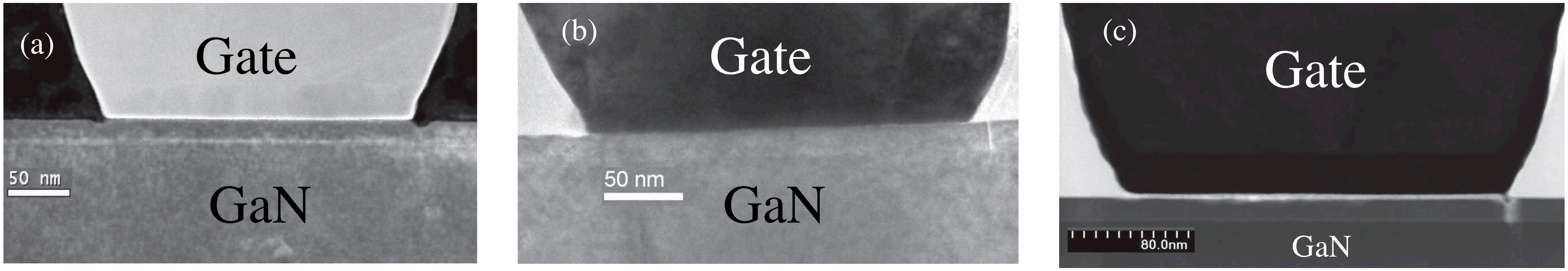


Objectives:

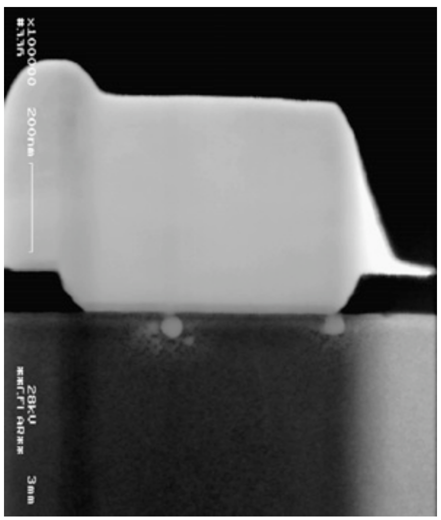
Develop a testing methodology for failure modes

Develop physical understanding of the failure modes

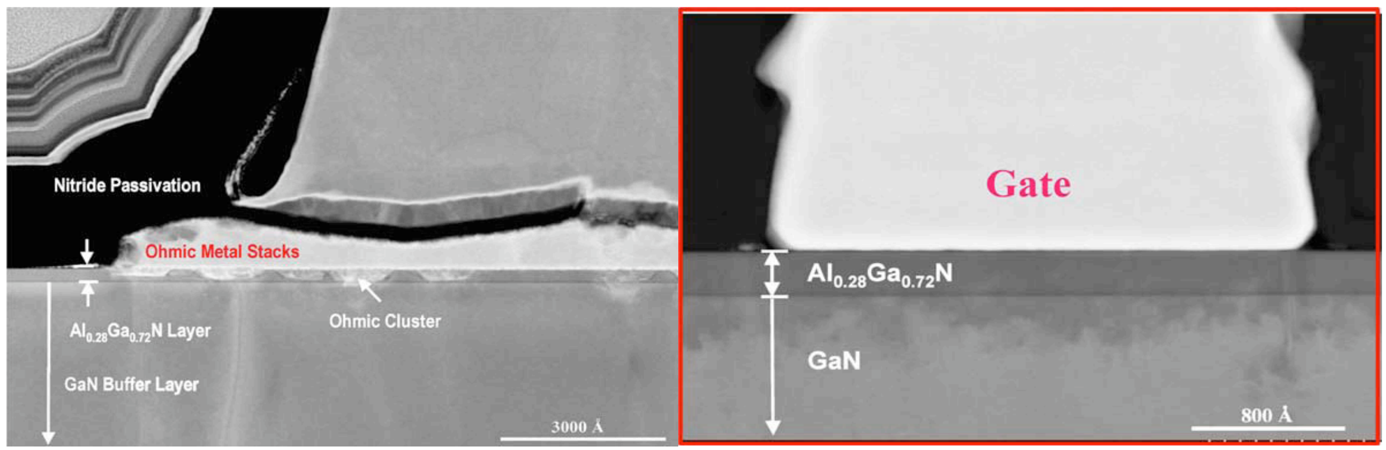
GaN X - Sections of Structural Failure Mechanisms



Chowdhury U et al. TEM Observation of Crack- and Pit-Shaped Defects in Electrically Degraded GaN HEMTs. IEEE Electron Dev Lett 2008; 29: 1098-1100.



Burgaud P et al. Preliminary reliability assessment and failure physical analysis on AlGaN/GaN HEMTs COTS. Microelectron Reliab 2007; 47: 1653-7.



Bright A N et al. Correlation of contact resisitance with microstructure for Au/Ni/Al/Ti/AlGaN/GaN ohmic contacts using transmission electron microscopy. J App Phy; 89: 3143-50.

Research Thrusts - Support Thrusts

- T1 Fabrication - Pearton
  - Several Industrial Partners
  - Like to have more
  - Local Fabrication capability for hypothesis testing
  - Partnering on test structures
- T2 - Statistical Support - Pearton, Law
  - Collaborate w/ Intel Reliability Team
  - Work with best Si techniques / approaches

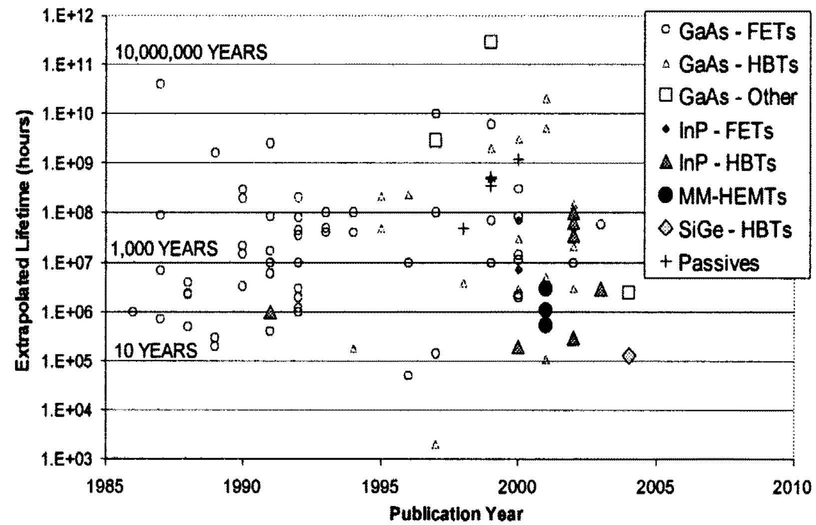


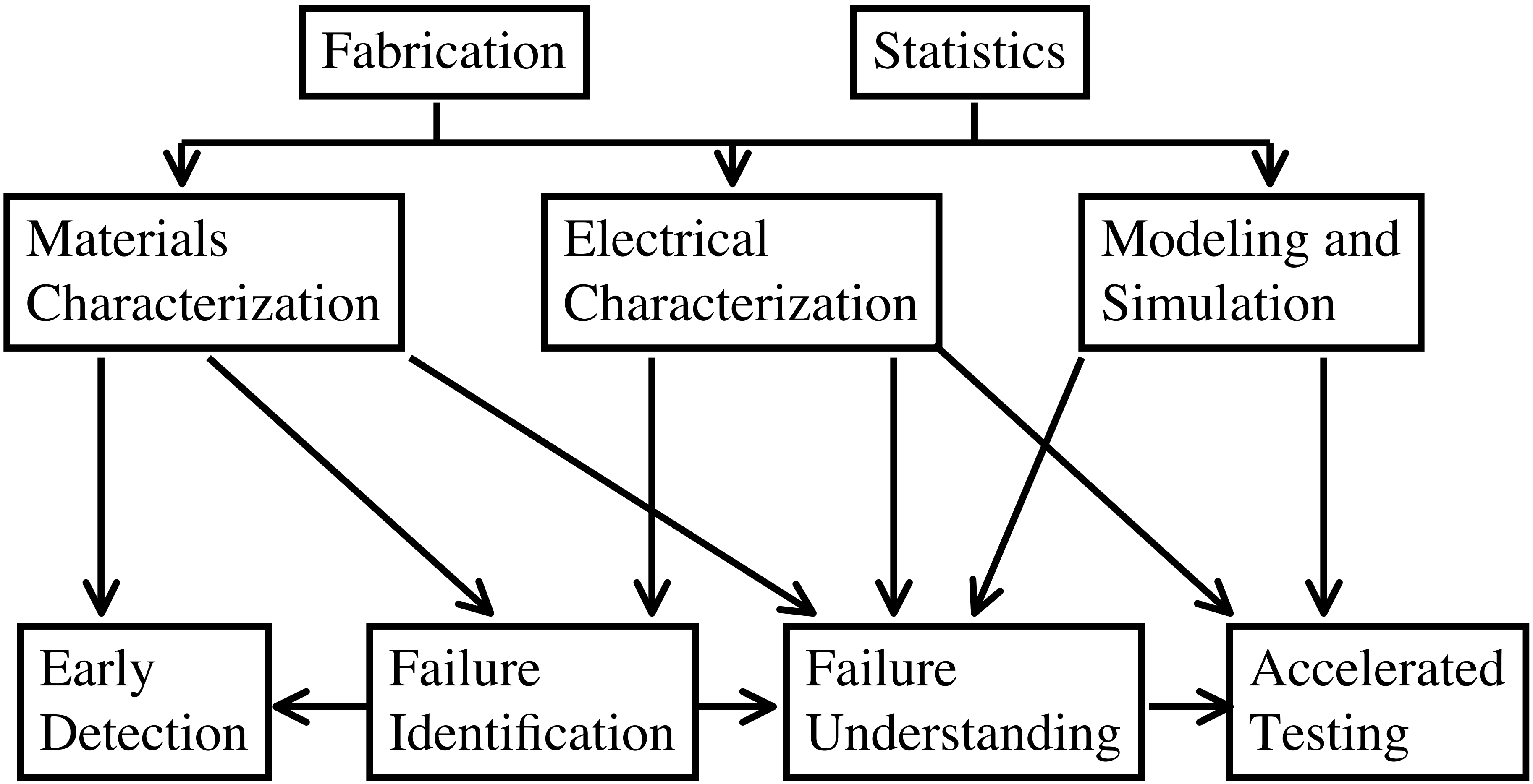
FIGURE 1. REPORTED OPERATING LIFETIMES FOR VARIOUS COMPOUND SEMICONDUCTORS OVER THE 19 YEAR HISTORY OF THE ROCS WORKSHOP[1]

Roesch, 2006

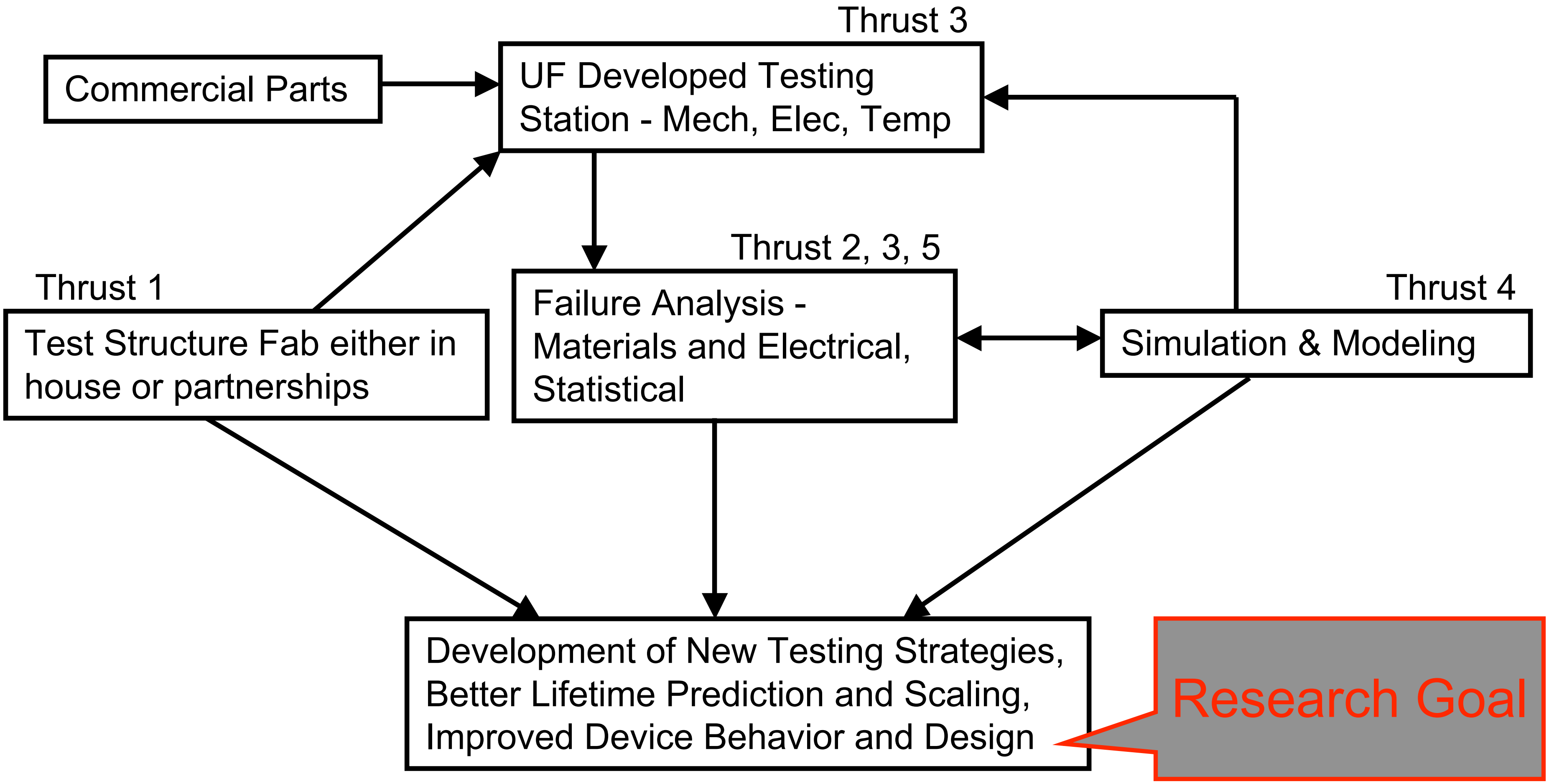
Research Thrusts - Primary

- Thrust 2 - Materials Characterization - Abernathy
  - Optical Techniques
  - Electron Microscopy
  - LEAP
- Thrust 3 - Electrical Characterization - Thompson
  - Burn-in and Tester Development
  - Mechanical Stress
  - Noise
- Thrust 4 - Modeling - Law
  - TCAD Extended Approaches
  - Noise
  - Mechanical Stress

Thrust to Problem Relationships



Research Work Plan



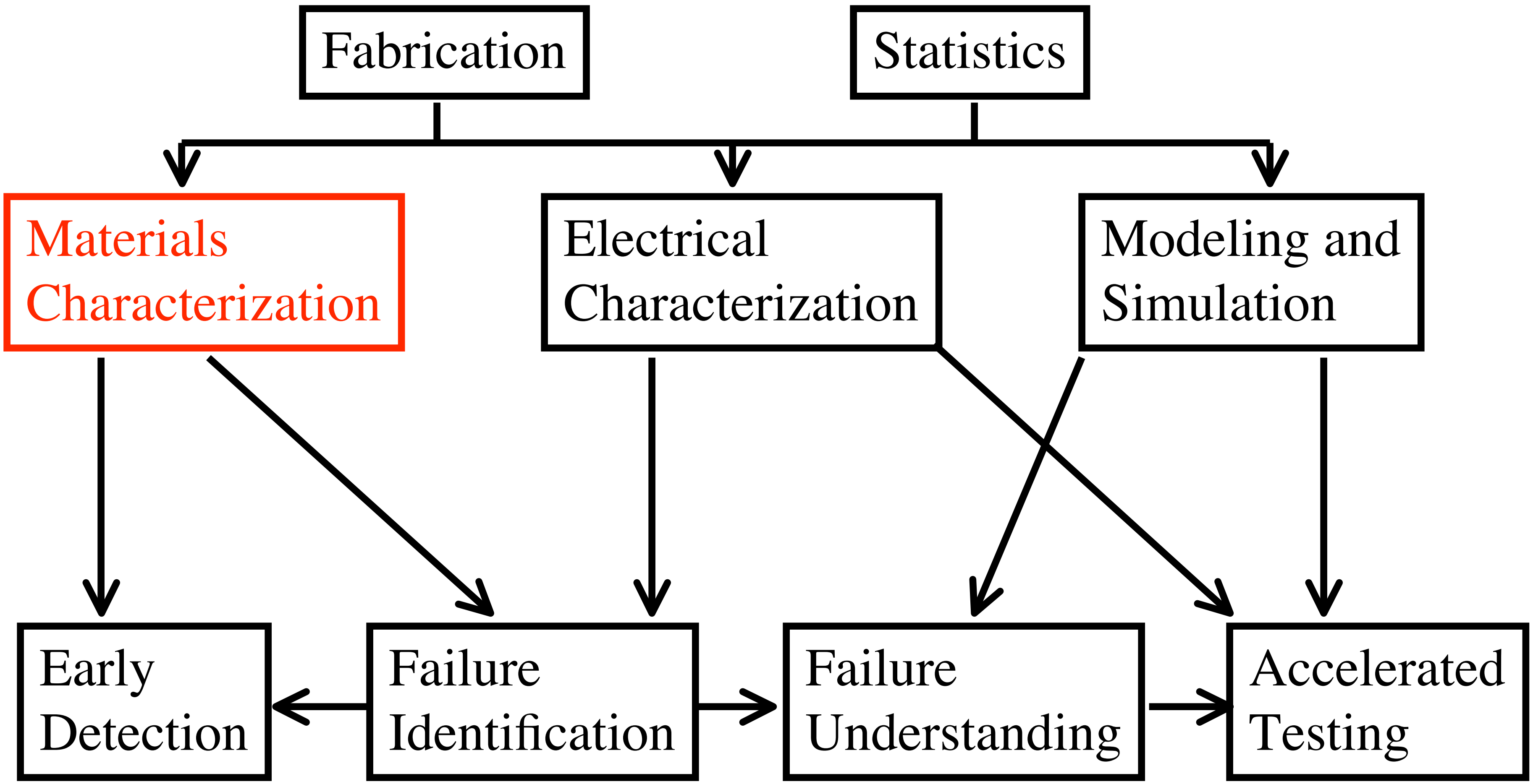
Collaborations with Industry

- **RFMD**
  - 77 stressed devices attached to RF boards
    - *Survived 1000 hour RFMD lifetime test in October 2008
  - 2500 unstressed devices
- **Nitronex**
  - 60 unstressed devices
- **WIN Semiconductor**
  - 20 unstressed devices
  - 8 stressed devices
  - 15 TLM strips
- **Northrop Grumman**
  - 3 unstressed devices

ITAR / Export Control

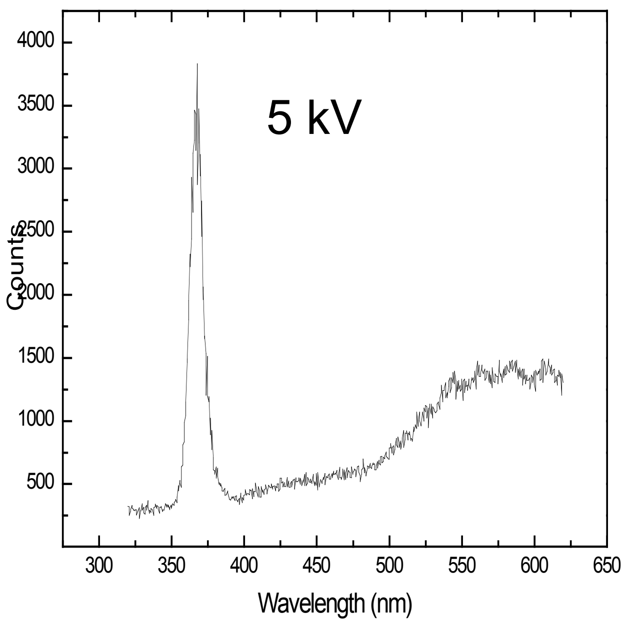
- Controlled Room in NRF
- Devices kept in locked room and locked cabinet
- Sign in / sign out for experimentation
- ITAR Training Provided

Materials Characterization Thrust

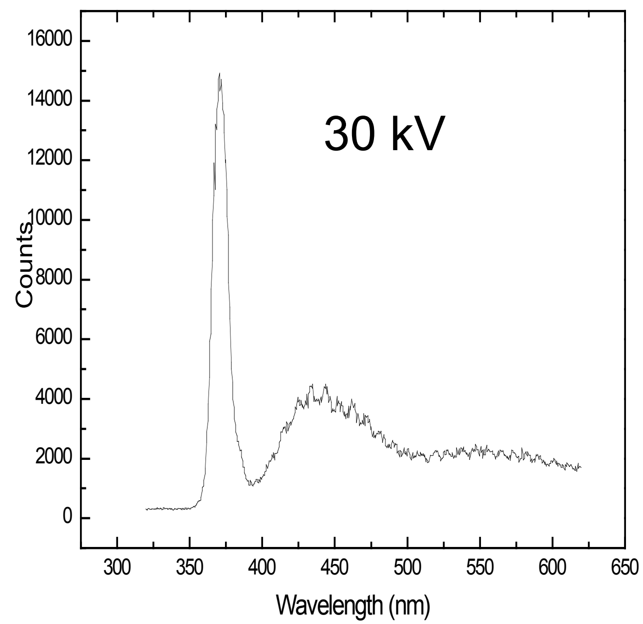


Depth Dependence of Emission Spectra (GaN Region)

UCF Chernyak System from GaN/AlGaN HEMT



~80-100nm below surface

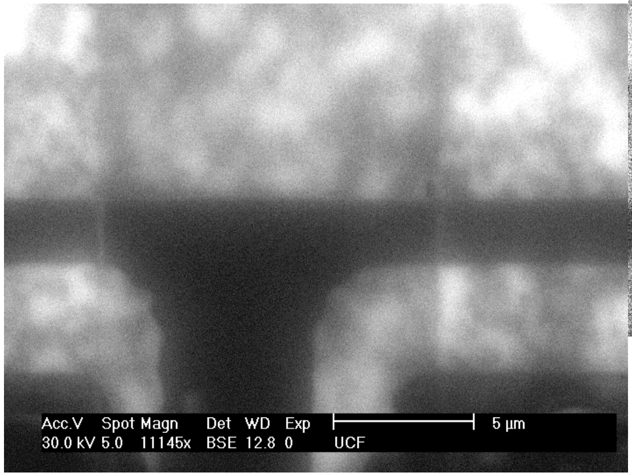


GaN Buffer

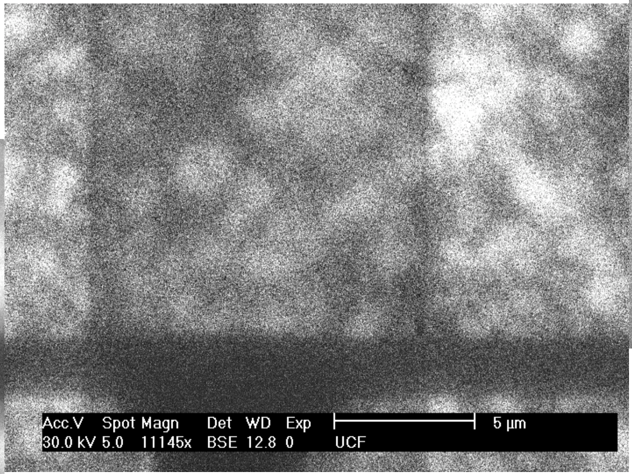
Wavelength Dependence of CL Emission

30 kV, 11kX

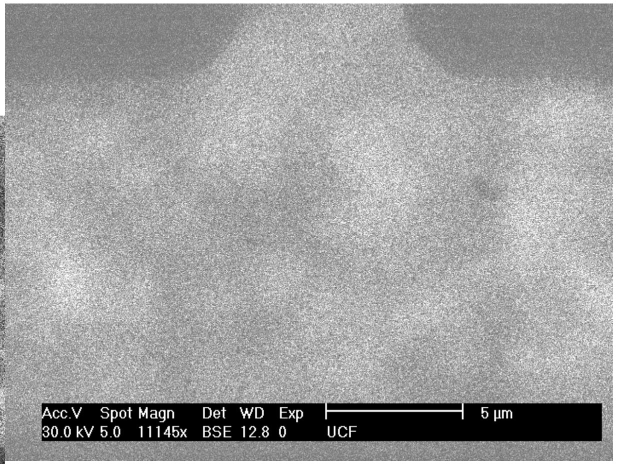
Panchromatic



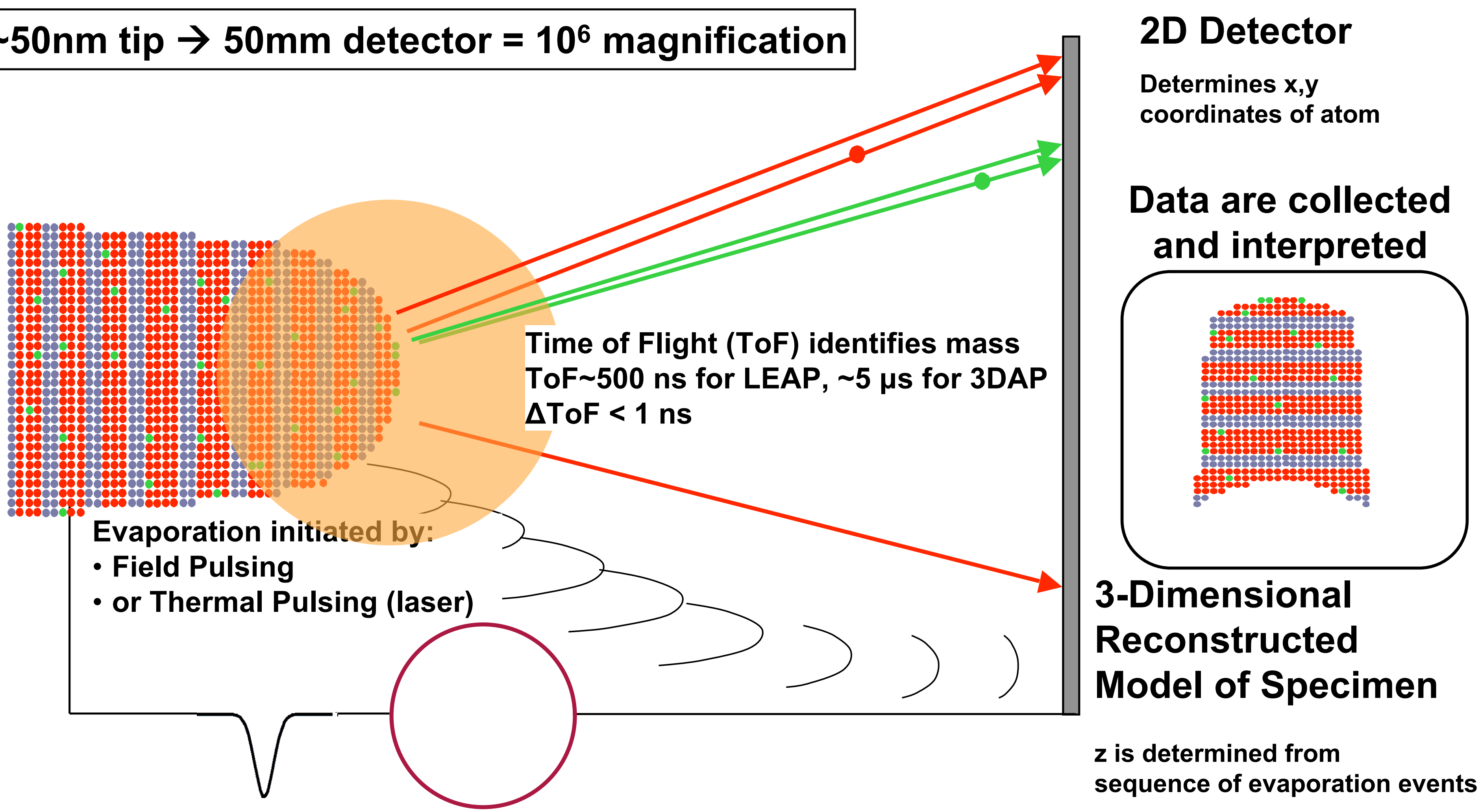
Bandedge



440 nm

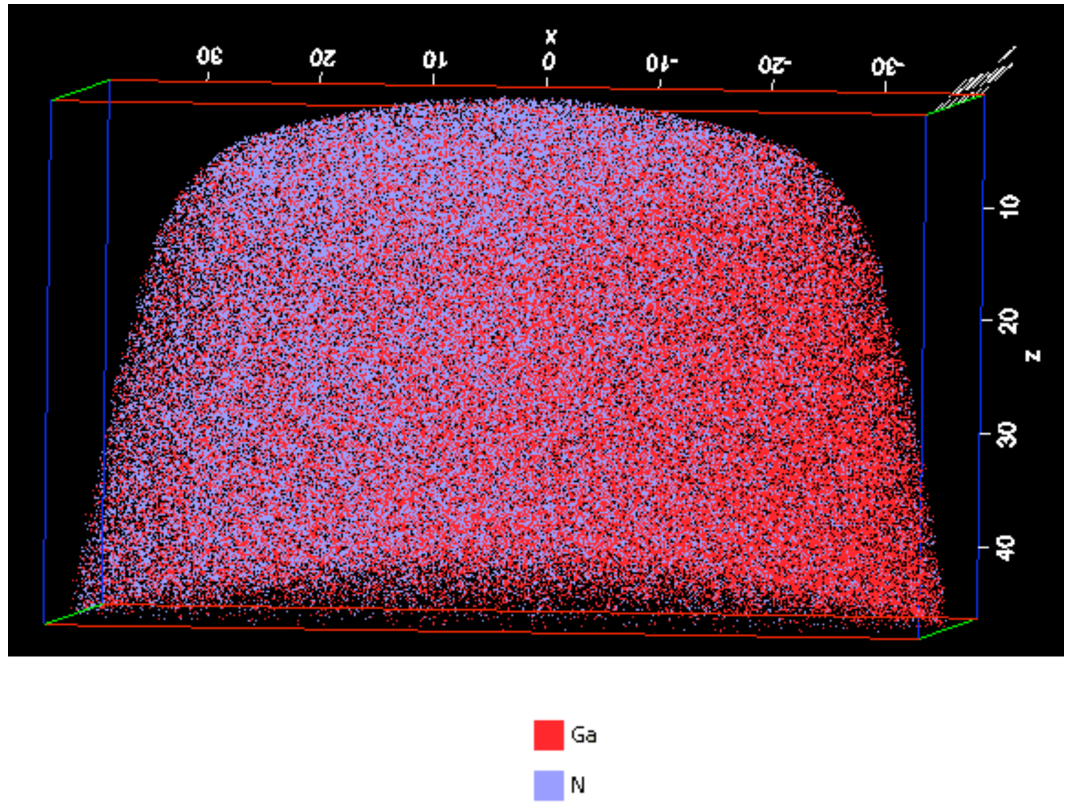


Local Electrode Atom Probe Operation

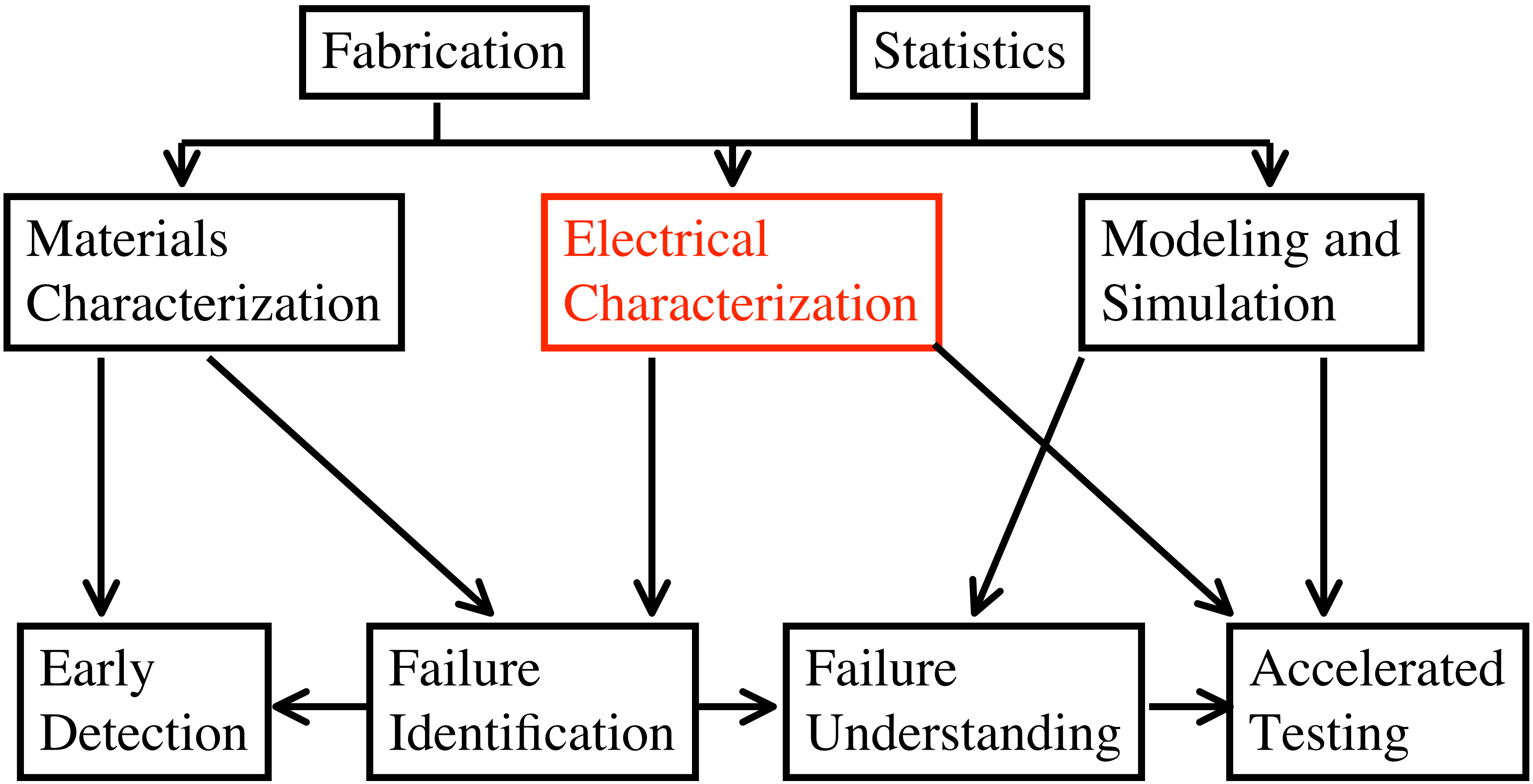


Preliminary LEAP Analysis

- First ever reported LEAP image from GaN
- Demonstrates that GaN can be analyzed by LEAP despite low conductivity
- 78,000,000 Atoms collected from this run
- Sample was run last week
- Data reconstruction and analysis still in progress
- LEAP reconstruction under gate



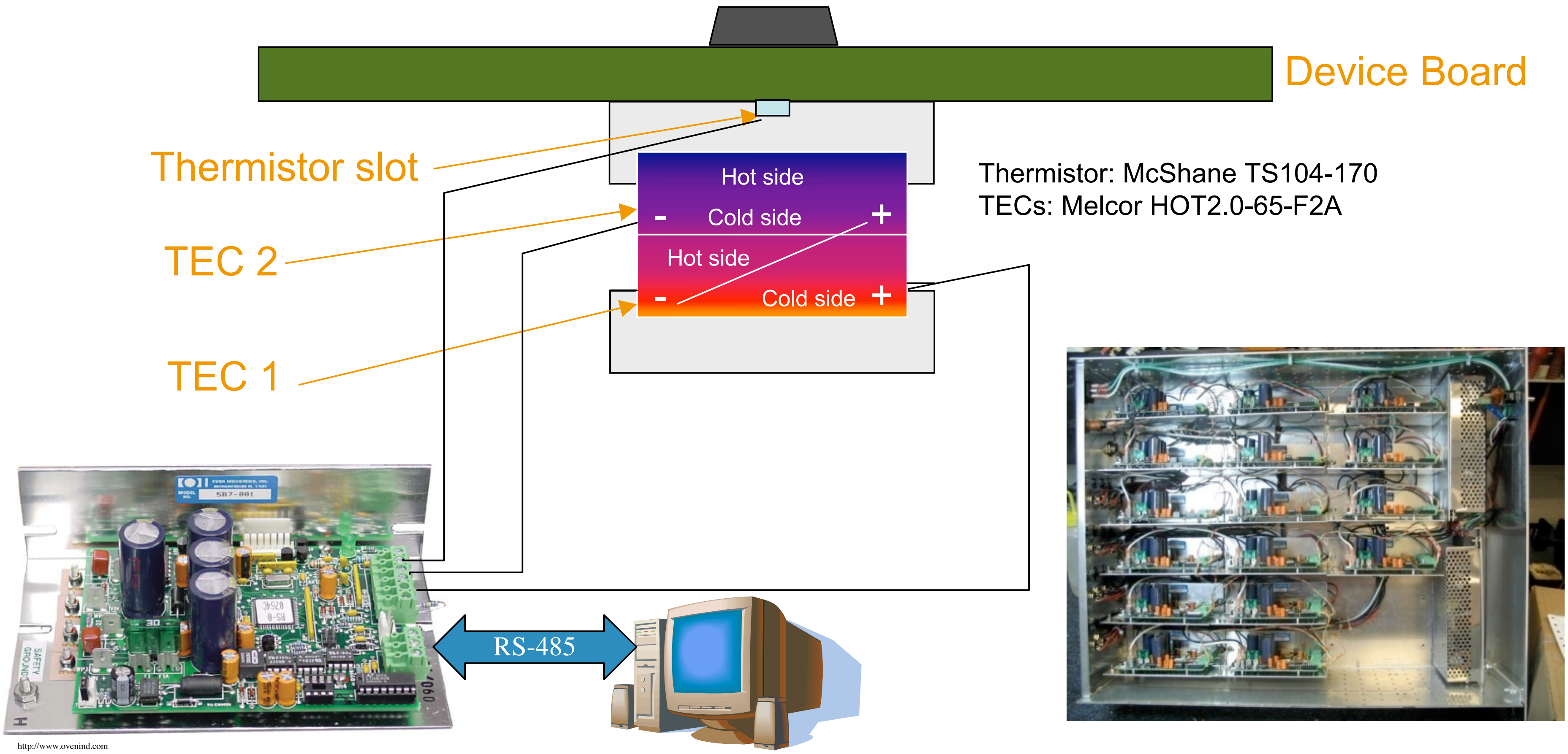
Electrical Characterization Thrust



Testing System Turnkey vs. In-house

	Turnkey	In-house
Timeline	Purchase lead time	On-going
System	Proven	Custom design
Objective	Determine Lifetimes	Research Determine failure mechanisms
Test Types	Industry standards	Flexible
DC Drain Gate	0-100V, up to 4A, 400W max ±18.5V, up to 200mA	0-60V, up to 6A, 300W max ±10V, up to 20mA
RF	600MHz-3 GHz 2-18 GHz 58-60 GHz 900MHz-10GHz 36-40 GHz 76-78 GHz	1.8-2.2 GHz expandable with additional hardware
Temperature	50° to 250° C	25° to 250° C
Optical	NA	Research with wavelength and intensity
Thermal Imaging	NA	IR, Micro Ramon additional hardware
Pulse	1-100kHz	Up to 80MHz
Data Storage	Independent test files	SQL database

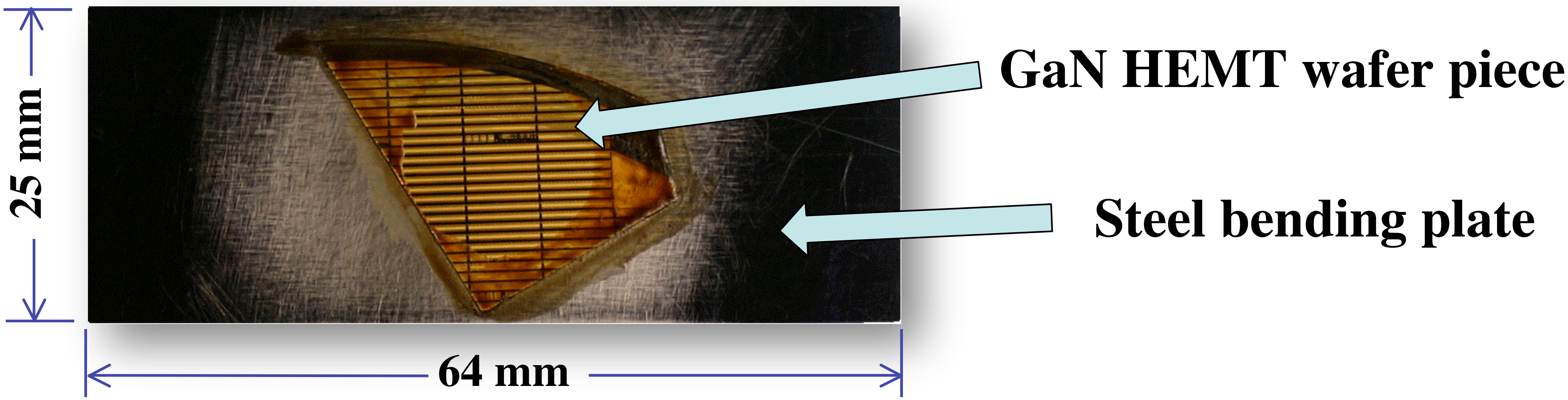
UF Semiconductor Reliability System

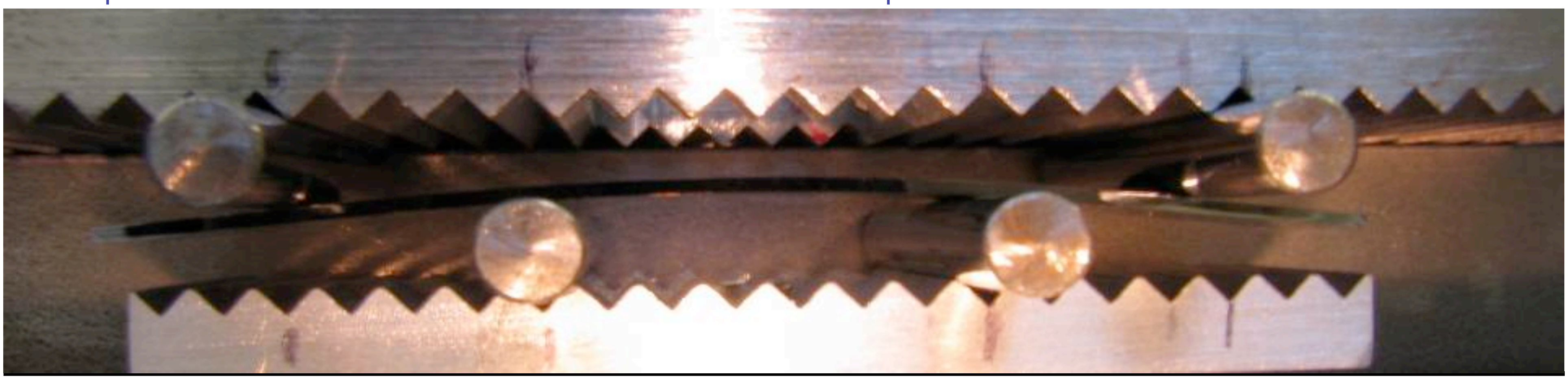


Temperature Measurement and Control

Strain Setup for GaN Commercial HEMT

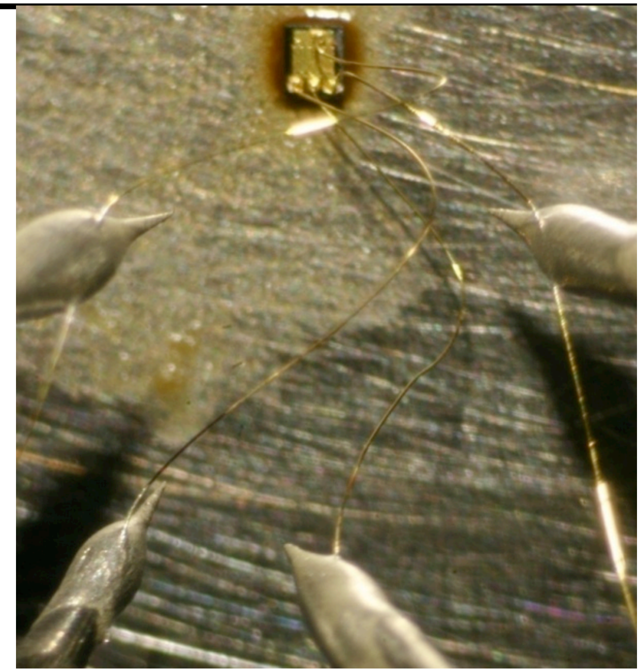
- GaN HEMT wafer samples too small to directly bend in 4-point bending setup
- Solution: (1) epoxy GaN HEMT wafer sample on high carbon stainless steel
  (2)calibrate achieved strain by strain gauge measurements



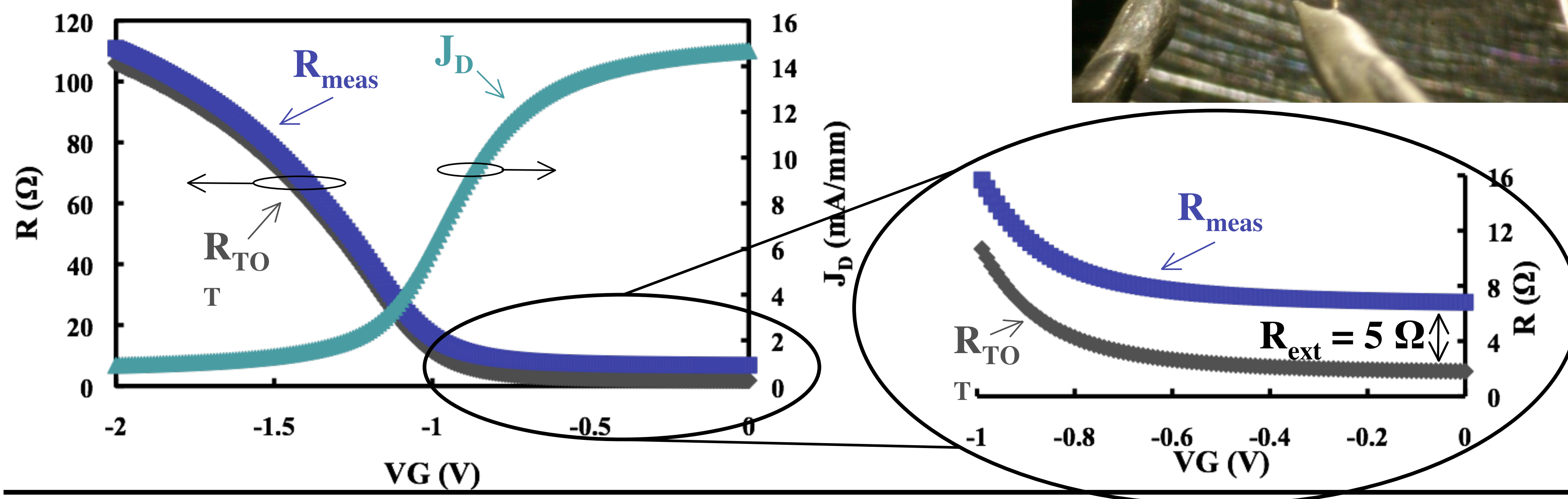


Strain Setup Measurement Technique

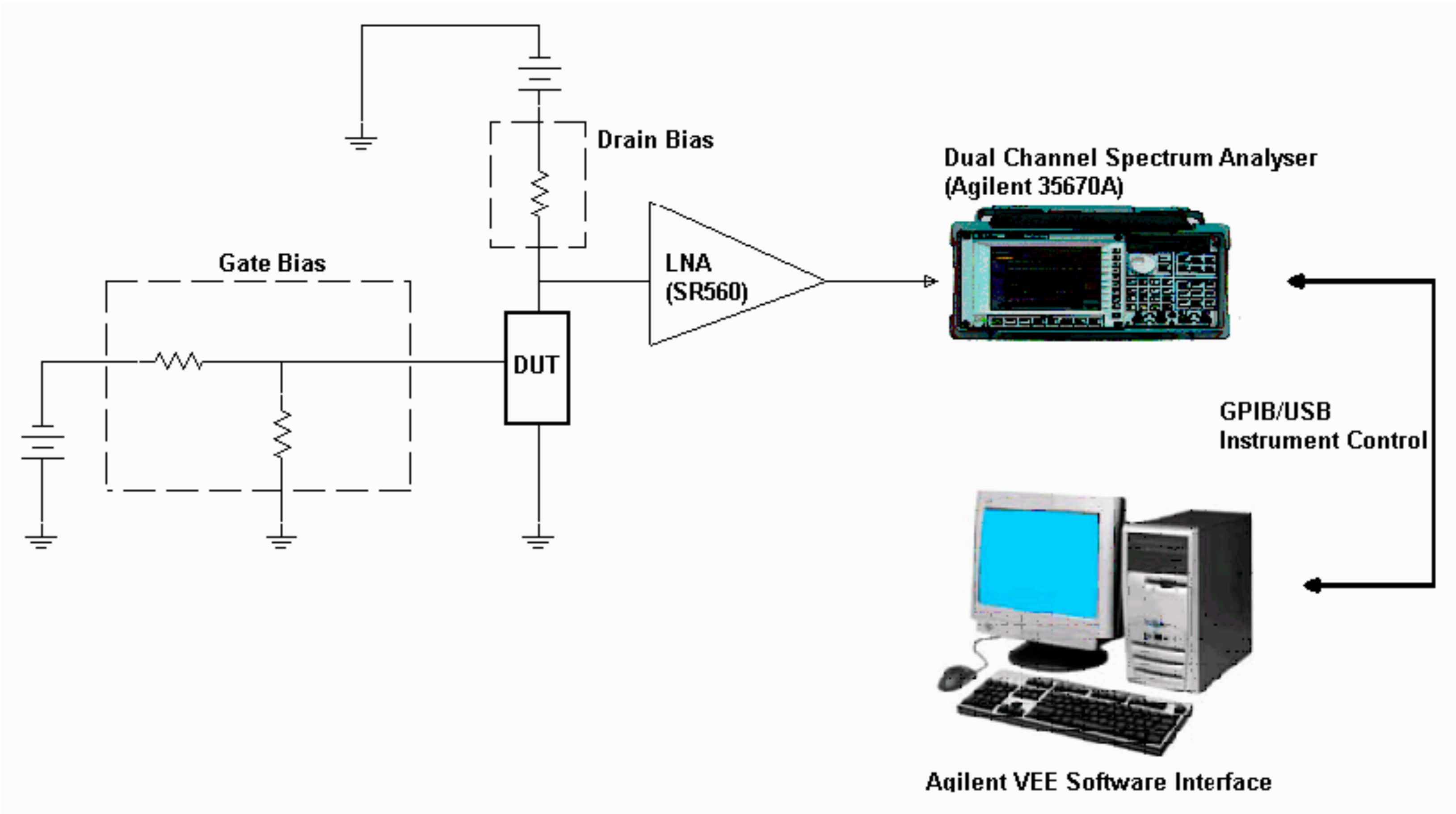
- Strain setup requires wire-bond to pads
  - Four-point measurement isolates channel resistance since R_{ext} comparable to R_{TOT}
    - Wide commercial device → small channel resistance
    - Wire-bonding and epoxy → large external resistance



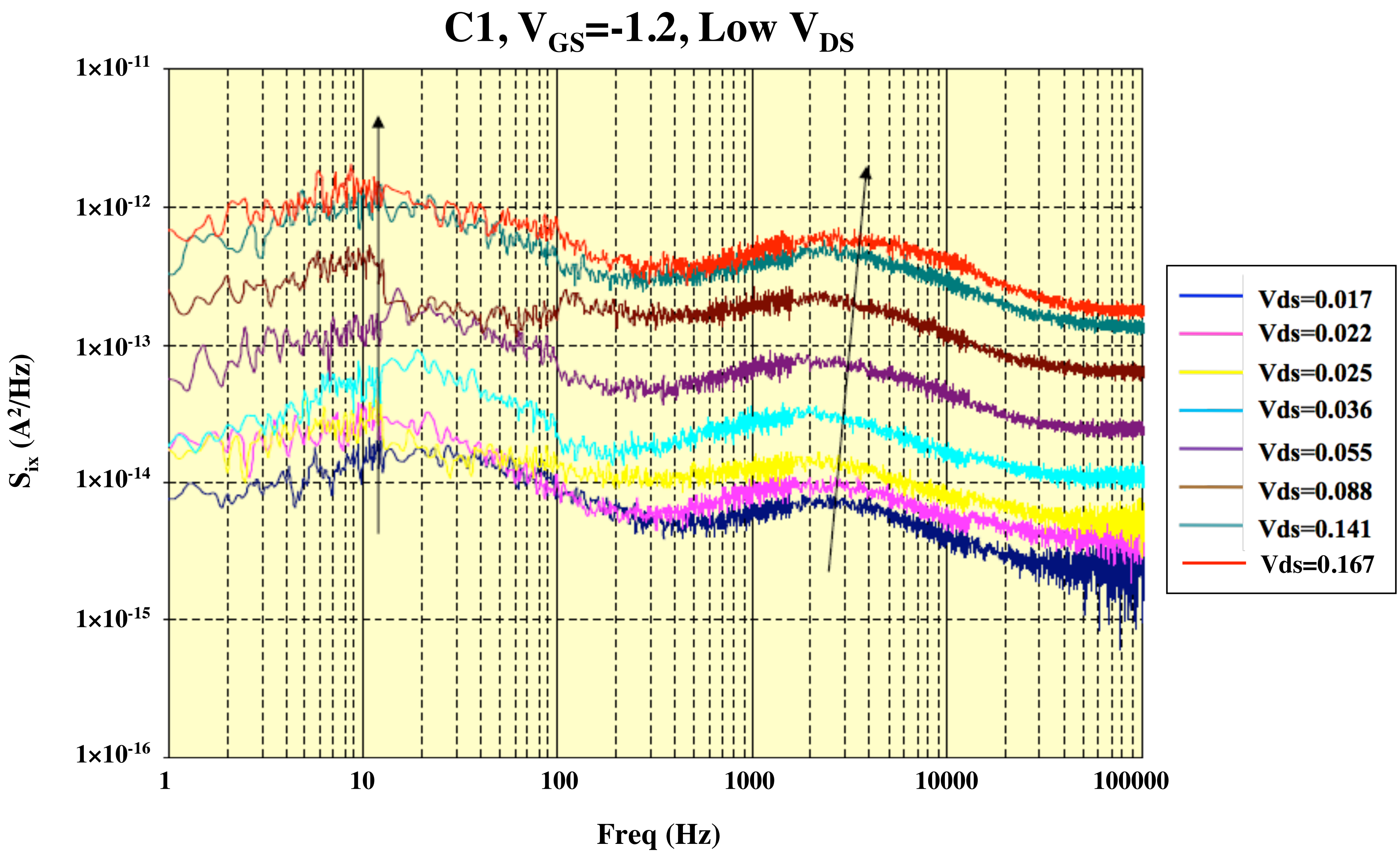
$\mathbf{R_{meas}} = V_{DS} / I_D = R_{TOT} + R_{ext}$
$\mathbf{R_{TOT}} = R_{CH} + R_S + R_D$ (extracted via 4-point measurement)



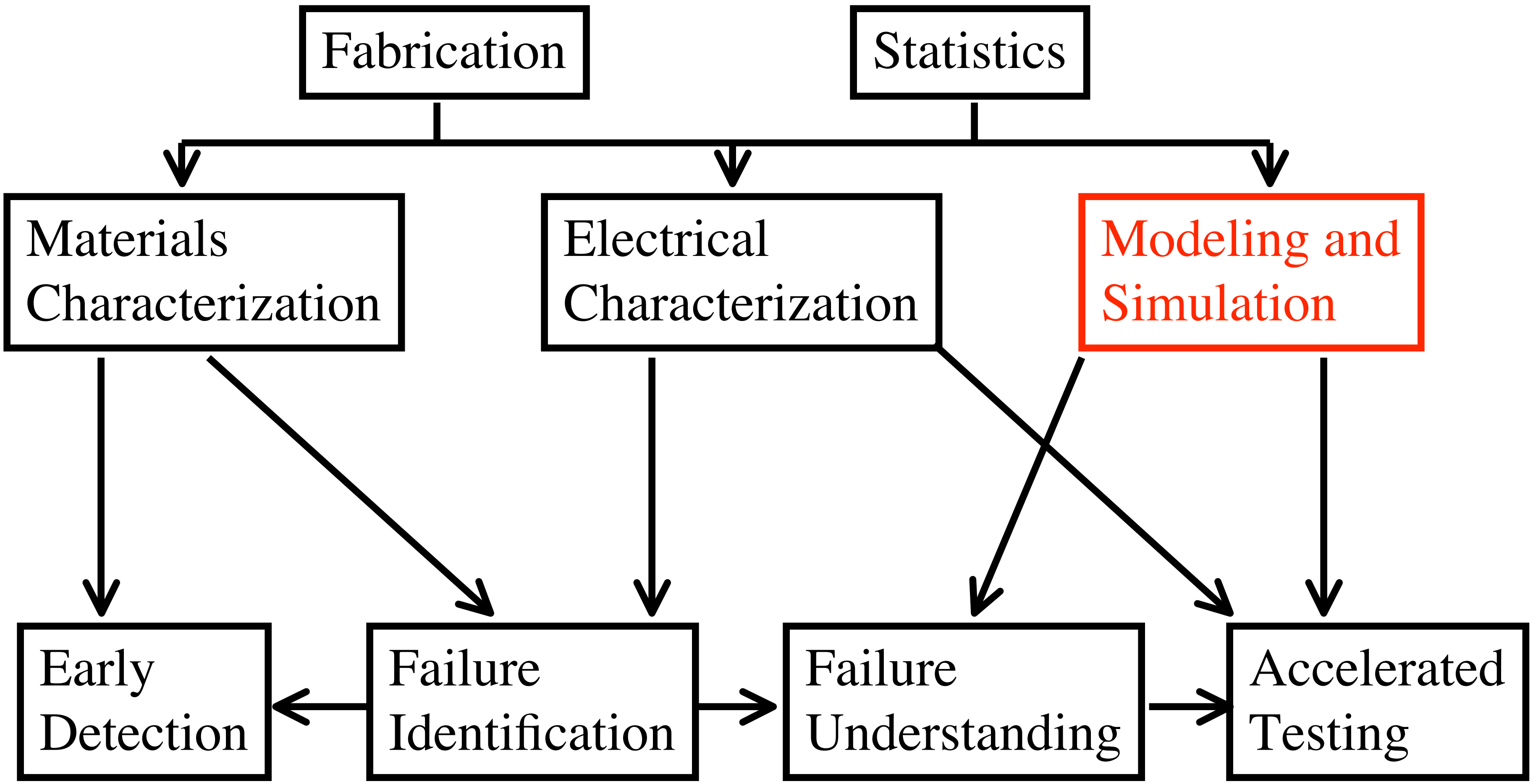
Noise Measurement Setup



Forward Drain Noise Data ($S_{id} \times f$)

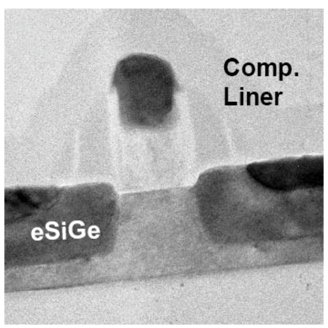


Simulation Thrust

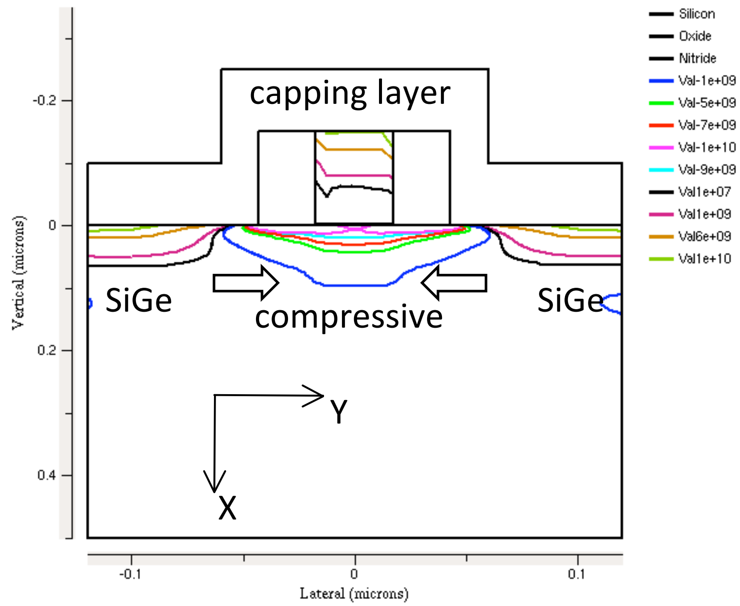


Strain Effects on Electrical Simulation

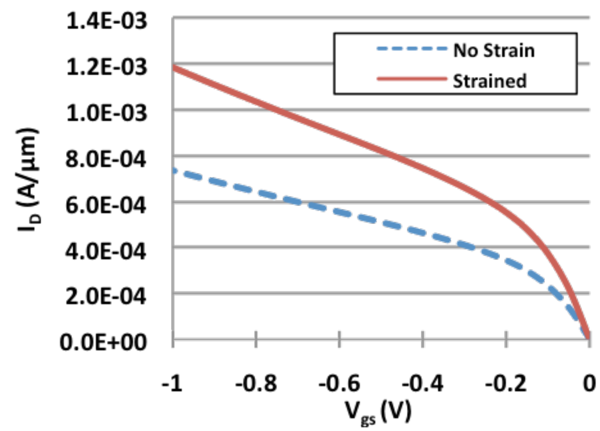
- To enhance channel mobility, PMOS strain processing includes embedded SiGe in the source/drain regions and compressive capping layers.
- FLOOXS predicts strain/stress profiles where the channel stress is ~1 Gpa
- Elastic strain is used to compute enhanced mobility



Horstmann, *et al.* IEDM 2005

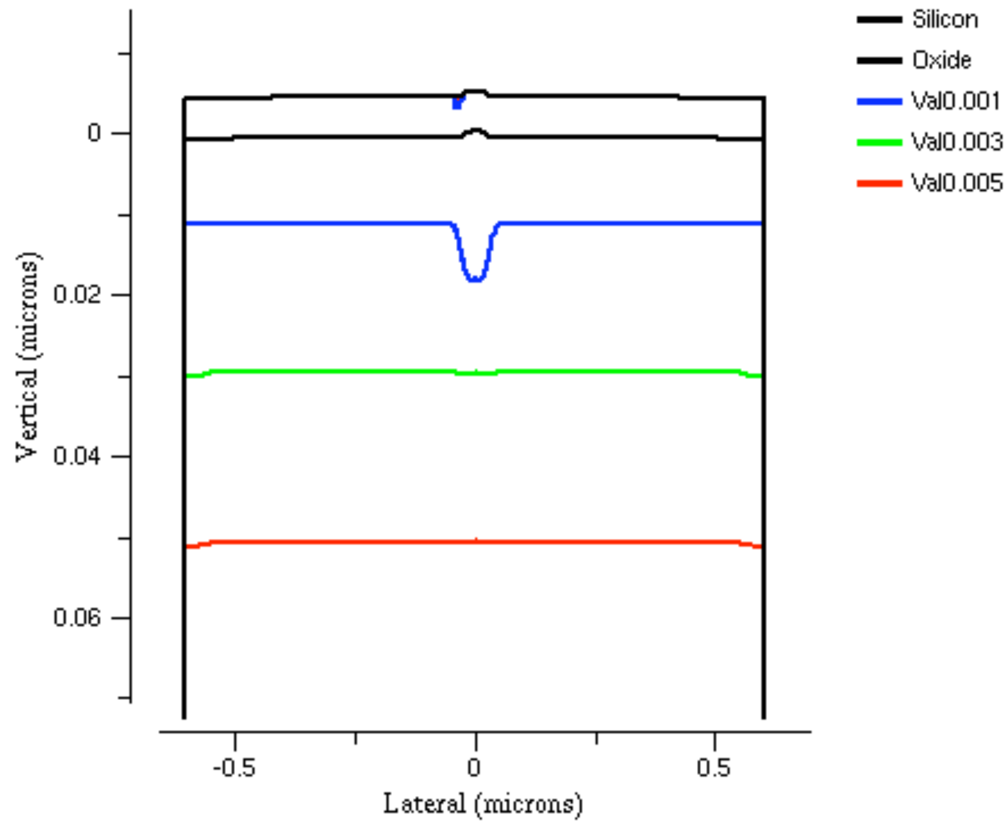


FLOOXS predicted stress profile [dyne/cm2]
(YY component - channel direction)



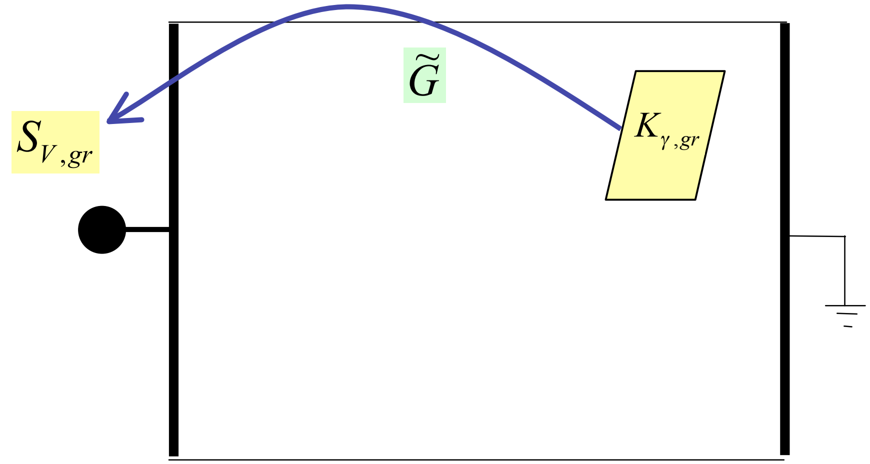
Electrical Effects on Strain

- Mechanical Simulation with Piezo Terms
- Simple test case - MOS Cap on Piezo Material
- Asymmetry in the strain due to change in direction in the horizontal field across the gate

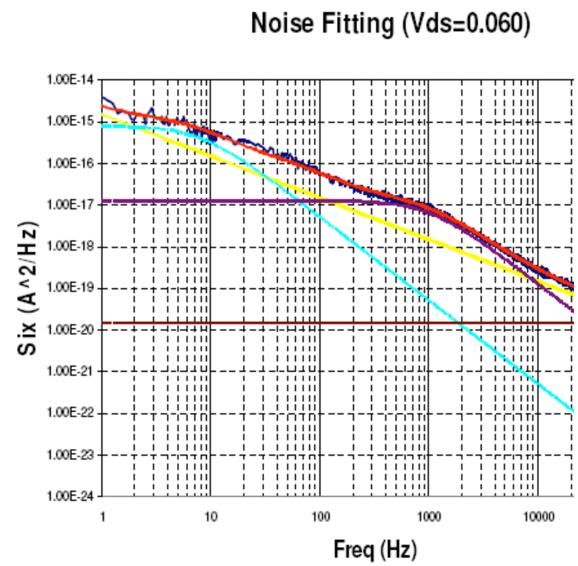


Noise Simulation Progress to date

The current version of FLOODS was upgraded, with the help of Juan Sanchez PhD, to include

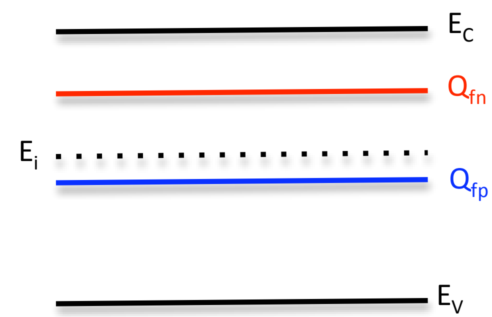


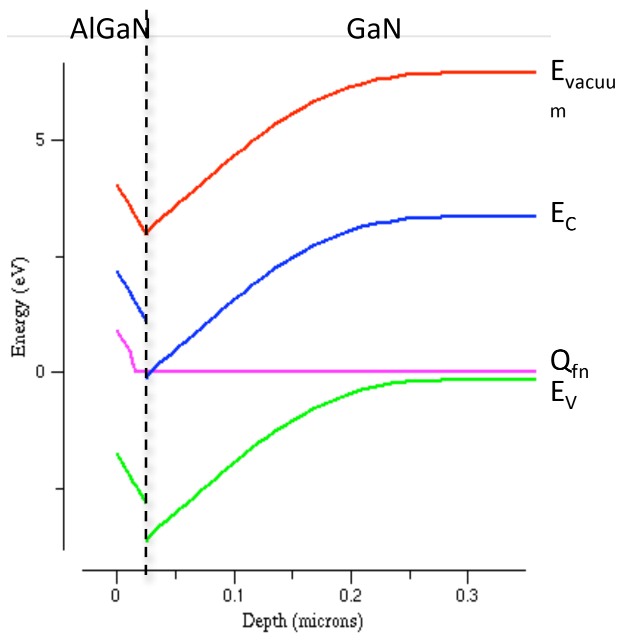
- Small signal AC simulation for calculating channel and transfer impedance and transconductance
- Velocity fluctuation and defect noise simulation
- External circuit elements

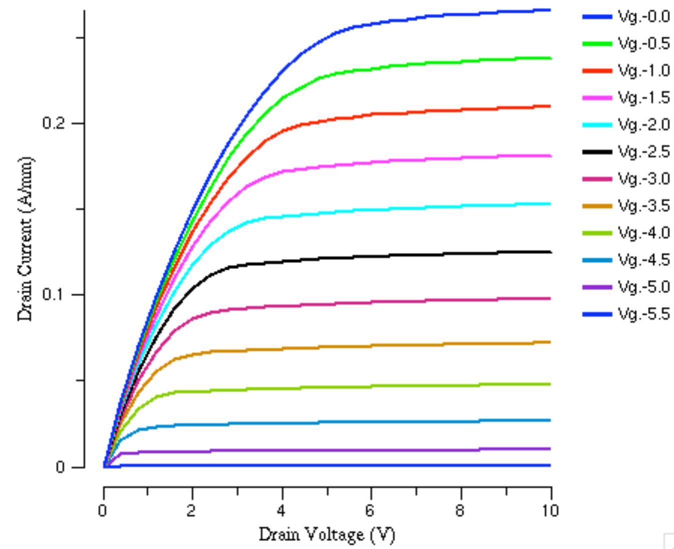


Device Simulation Approach

- Quasi-Fermi levels approach for solution variables
- Current flow defined on elements
- Consistent with mechanical properties



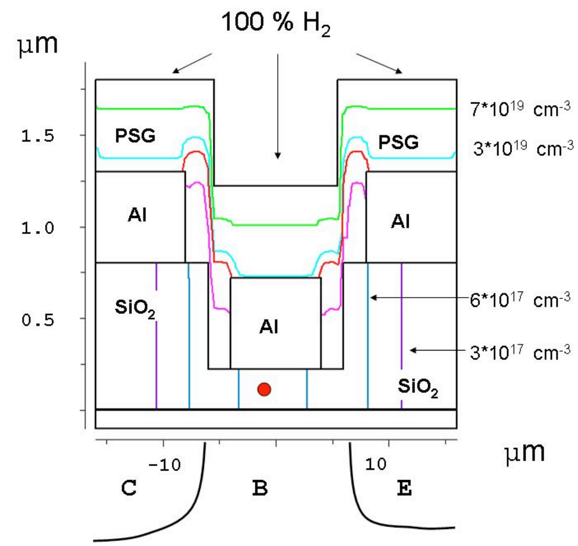




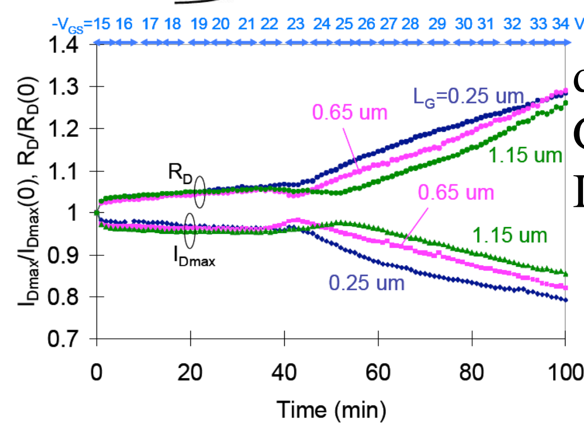
Interface charge 1.2e13
Dependent on Strain

Collaborations w/ DRIFT and Others

- Vanderbilt
  - Surface Degradation
  - Hydrogen Behavior During Device Operation
  - Existing Collaboration on Radiation Effects
- MIT
  - Overlapping Interest in Stress
  - Share data and models
- Georgia Tech
  - Sharing devices, data



TNS, TBP



del Alamo Group, 2006 IEDM

Fig. 11. Gate length dependence of degradation. Different gate length devices (type A1, L_G=0.25, 0.65, and 1.15 um) are stressed at V_{DS}=0 and V_{GS}=-15~-34 V (-1 V step, 5 min/step). The threshold of the degradation increases with L_G.

Conclusions

- Science Based Program
- Directed at:
  - Improved Testing Methodology
  - Greater Understanding of Failures
  - Failure Prevention Strategies
- Strong Collaborations
  - Industry
  - University Partnership